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AN EVALUATION OF MANATEE DISTRIBUTION PATTERNS IN RESPONSE TO PUBLIC USE ACTIVITIES IN KINGS BAY, CRYSTAL RIVER, FLORIDA

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INTRODUCTION

Manatees are tropical and subtropical aquatic mammals that belong to the order Sirenia. Worldwide, there are three species of manatees, the West Indian (Trichechus manatus), the Amazonian (T. inunguis) and the West African (T. senegalensis). A related Sirenian genus, the dugong (Dugong dugon) inhabits the waters of Australia and the Indo-Pacific Ocean. The Steller's sea cow (Hydrodamalis gigas), a large Sirenian which occurred in the Bering Sea, was hunted to extinction by the year 1766, only 25 years after its discovery ((Packard et al., 1984). Throughout their history, manatees have been hunted by humans for their meat and their dense ivory-like bones. Today they are considered either rare or endangered throughout most of their range. In most parts of the world, human danger to manatees comes from accidental entanglement in fishing nets or from subsistence hunters who intentionally trap or harpoon the animals (Lefebvre et al., 1989). In the United States, however, the greatest dangers come from boats, which each year inflict injury and death on a significant number of animals. Speed boats strike them at high speed, sometimes killing them by impact or propeller wounds. Barges strike them or crush them against the bottom. Manatees in the U.S. are also crushed in locks, tangled in or swallow fishing lines and occasionally are butchered (Brownell, 1980; 1981). They also may ingest chemicals from urban runoff and aquatic weed control (O'Shea, et al., 1984).

In recent years a more subtle hazard has emerged. Boaters, divers and snorkelers have learned that manatees can be easily

approached in their winter ranges. The growing popularity of manatee encounters has led to an increase in the density of people boating, diving and snorkeling in some areas. In one area, Kings Bay, Crystal River, in Citrus County, Florida, there has been growing concern that the welfare of manatees is being adversely affected by the level of waterborne activities.

Nationwide publicity about the manatee has increased awareness of its plight, but also has attracted an increasing number of people to Crystal River each winter to see and interact with the endangered animals. Most of these visitors rent boats and many rent SCUBA or snorkeling gear. Nearly all manatee seekers center their activities in the southern end of Kings Bay, near King's Spring, the largest spring in the bay. It is there that the greatest number of manatees can usually be found. The manatees in the South Bay are seeking the warmth of the springs. Residents, visitors, biologists and managers have become increasingly concerned that high-density human water-related activities (mostly boating, diving and snorkeling) in this area may be negatively affecting the normal behavioral patterns of the manatees. Manatees have been observed to dive or turn when approached by a motorboat. A few manatees are attracted to anchored boats and may even chew or play with anchor lines. Some manatees are attracted to snorkelers and roll on their backs to be scratched. The majority of manatees, however, ignore human attention or appear to avoid it by moving into the manatee sanctuaries or swimming out into colder portions of the bay (Patrick Hagan, pers. comm.).

The reactions of individual manatees, although easily seen, are difficult to quantify. They suggest, however, that human waterborne recreational activities may affect a large proportion of manatees wintering in Kings Bay. A study to determine the nature of this interaction was proposed by Packard (1983), by the Florida Manatee Recovery Team (USFWS, 1989) and by Project Leader Glenn Carowan of the Chassahowitzka National Wildlife Refuge complex. To evaluate the impact of human activities on manatees in Kings Bay, I investigated changes in manatee abundance and distribution in response to different levels of human use.

The study had the following objectives:

1. To observe the manatees that use Kings Bay, Crystal River, Florida throughout the winter and to plot their relative use of southern end of Kings Bay (South Bay) and its sanctuaries on days with differing levels of human activity.
2. To determine the relationship among human waterborne activities, temperature, and manatee use of Kings Bay.
3. To make management recommendations, if necessary, to minimize any negative impacts of human water-borne activities on the Crystal River manatees while they are using this critical winter habitat.

STUDY AREA

Kings Bay and the city of Crystal River are located on Florida's west coast in the Big Bend area, approximately 150 km (90 miles) north of Tampa (Fig. 1). The bay is approximately 1 km (0.625 miles) wide and 2 km (1.25 miles) long. It contains several large springs, most notably the cluster around King's Spring south of Banana Island, and numerous smaller springs which together form the headwaters of the Crystal River (Figs. 1 and 2). The 11 km (6.6 mile) long river empties into the Gulf of Mexico.

The total output of the springs is affected by tides and rainfall. The average output from 1964-1975 was estimated to be 25.9 cubic m or 2.25 million kl (600 million gal.) of water per day (Hartman, 1974). Because the springs are fed by the Floridan Aquifer, the water issuing from the springs remain a constant 23.7°C (74.7°F).

Most of Kings Bay is between 1 and 3 m (3 to 9 ft) deep with the exception of some of the larger springs, which are 10 m (30 ft) or more in depth. A study presently underway by the Southwest Florida Water Management District (SWFWMD) should reveal the effects of tidal influences on the bay's salinity. Tides also can cause up to 2 m (6 ft) of variation in depth (Hartman, 1974) but the typical daily variation is about 1 m (3 ft) (Jim Reid, pers. comm.). Strong winds seem to accentuate or counteract tidal influences and hurricanes can greatly increase the tidal effect and may drastically increase salinity (Rosenau et al, 1977).

The South Bay, defined as the area of approximately 120 hectares (300 acres) south of Banana Island and Warden Key, contains King's Spring (also called the Main Spring) and neighboring springs. These springs are considered to be responsible for the largest outflow of warm water in the bay. King's Spring itself is around 22 m (75 ft) across, with a 9 m (30 ft) deep hole. Two entrances at the bottom lead to a 15 m (50 ft) wide cave that is 18 m (60 ft) deep. The flow of water from this spring is light. Stronger flows issue from both Grand Canyon Spring, a 10 m (35 ft) long crack adjacent to King's Spring and Mullet's Gullet, a series of small springs 30 m (100 ft) east of King's Spring (DeLoach, 1986). Banana Island and Warden Key may help protect the South Bay from wind and tide driven currents that would mix with and cool the warm water.

The study area consisted of a portion of Kings Bay south from the middle of Buzzard Island including the canal system fed by Magnolia Spring (Figs. 1 and 2). The area covered by the aerial surveys was about 2.4 km (1.5 mi) by about 3.2 km (2 mi) and contained about 405 ha (1013 acres) of water. The area contained all three manatee sanctuaries, the two largest springs (Magnolia Spring and the King's Spring cluster) and the South Bay area described above (Fig. 2).

The principal downtown area of Crystal River is on the northern and eastern shores of Kings Bay and the area around the bay is developing rapidly. Much of the bay is surrounded by subdivisions and most of the shoreline has seawalls. Dredge and

fill operations have modified the eastern and southern shore of the bay. However, the freshwater marsh on the western shore remains virtually undeveloped.

Many of the houses in the subdivisions have boat docks and residents are requesting additional dock and building permits on the bay and the river. Both Sunset Shores and Magnolia Springs manatee sanctuaries have docks within their boundaries and additional dock-building could occur if permits were obtained. Local residents and guests are allowed direct boating access to and from their docks.

The number of boats using Kings Bay is increasing. During the winter months, the number of boats clustered around the South Bay's main spring and the adjacent two manatee sanctuaries has increased. Packard (1983) reported as many as 33. Public use reports from the Crystal River National Wildlife Refuge for the last few years indicate that the presence of 50 or more boats in this area is no longer uncommon.

Kings Bay is an increasingly popular year-round SCUBA diving resort. Dive instructors from both in- and out-of-state often bring classes to Crystal River for open-water diving certifications and, in winter, for manatee encounters. Large numbers of people also come independently for diving, fishing, snorkeling and recreational boating opportunities. The tourists using Kings Bay produce significant revenue for the city, particularly for the local dive shops, marinas, restaurants and motels which cater to waterborne recreational activities. As public use has increased,

so have revenues. For five dive shops and three motels closely associated with Kings Bay, total sales more than doubled between 1980 and 1986 (Milon, in prep.). The first quarter of the year (January-March) is the period when most dive shop operators feel the presence of manatees most influences their business. In each of the six years above, sales during the manatee season accounted for between 28 and 53% of the sales for the entire year (Milon, in prep.).

As the number of residents and tourists increase so does the public pressure to control aquatic weeds, such as Hydrilla and the algae Lyngbya, which limit the use of the county's waterways. As a result, Citrus County has the third largest public aquatic weed control program in Florida (Center for Aquatic Plant Research, 1987).

Since the 1960's manatees have been known to use Kings Bay as a winter thermal refuge (Hartman, 1974) and the maximum number of animals aggregating in the bay has been steadily increasing. Hartman (1974) reported 63 animals present in the area during the winter of 1967-68 whereas the Crystal River National Wildlife Refuge reported 162 in Kings Bay alone in December 1987. At this time, the largest manatee aggregations known to occur in a natural warm-water refuge are found in Kings Bay (Kochman, et al., 1985).

The Crystal River National Wildlife Refuge (part of the Chassahowitzka NWR complex, administered by the U. S. Fish and Wildlife Service) was created in 1983 specifically to protect the manatee in the midst of these potential impacts. However, the

43-acre Refuge consists only of nine undeveloped islands, the submerged lands associated with them (including the largest spring, referred to as King's Spring) and a few scattered lots (mostly undeveloped) on the mainland. The greater part of the Kings Bay shoreline is privately owned. With the exception of a small area owned by the federal government, the water bottom and the water column belong to the State of Florida. The Refuge has no direct control over developments that occur anywhere other than on Refuge lands.

However, as an endangered species, the manatee falls under the protection of the Endangered Species Act of 1973 which makes the "taking" of an animal unlawful. One category of "taking" is "harassment". Harassment is defined in the Act (50 CFR 17.3(c)) as "an intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavioral patterns which include, but are not limited to, feeding or sheltering." Refuge Law Enforcement authority gives the officers of the Crystal River NWR the authority to enforce any regulations concerning harassment of the manatee whether they are technically on Refuge property or not. The Refuge is empowered to:

1) Enforce state and federal laws related to the Endangered Species Act and the Florida Manatee Sanctuary Act. These include harassment violations, speed zone regulations and sanctuary violations. (The Refuge cannot enforce county

or local laws, although an effort to change this is being made.)

2) Monitor the Big Bend manatee population, in cooperation with the USFWS Sirenia Project, National Ecology Research Center, Gainesville, FL.

3) Monitor positive and negative effects on manatees, including impacts on vegetation, water quality, and human recreational activities.

4) Provide interpretive education opportunities to the public.

5) Serve in an advisory capacity by providing information and recommendations for the protection of the manatee to the FWS Enhancement Office in Jacksonville which in turn provides biological opinions to the Corps of Engineers as well as leadership for other manatee recovery activities.

6) Implement emergency measures, such as extending the dates that idle speed zones or manatee sanctuaries are in effect in response to weather conditions and corresponding changes in manatee use patterns.

If the existing level of human recreational activity in Kings Bay constitutes harassment of the manatee population, the Endangered Species Act requires the U. S. Fish and Wildlife Service to take steps to correct the situation.

MATERIALS AND METHODS

To determine the number and distribution of manatees and boats on days of differing levels of human use, simultaneous ground and aerial surveys were conducted on two mornings each week from January through March 1988 and November 1988 through March 1989. Beginning at first light, or as soon afterward as possible, five 20-30 minute surveys were flown in fixed loops over the study area at one hour intervals. Based on Packard's (1985) recommendations, aerial surveys were flown in a Cessna 172 airplane at an altitude of 150-225 m (500-750 ft) and an air speed of 128 km/hr (80 mph). On two occasions a Cessna 172 was unavailable and a Cessna 152 was used. Altitude and air speed remained the same. Unexpectedly, the FAA canceled the project's waiver to fly below 300 m (1000 ft) because of complaints by nearby residents. Therefore, surveys after December 24, 1988 were flown at 1000 ft. Crystal River Refuge Biologist Larry Hartis, who has flown the surveys for the Refuge for the past four years, believes the 300 m (1,000 ft) altitude did not reduce the accuracy of his counts. On six days the Refuge surveys coincided with those of this study. The counts were within 5% of each other on these dates.

During aerial surveys, one observer counted manatees while the other counted boats. Three individuals alternated as manatee observers over the course of this study and a total of eight others counted boats. Manatees and boats were plotted on separate grid maps by the observers. Manatees were categorized as being adults (large) or calves (small and associated closely with an adult).

Boats were divided into three size categories: Small: canoes, kayaks, rubber boats - boats capable of carrying about 3 people; Medium: jon boats - boats less than 20 feet long, capable of carrying between 4 and 8 people; and Large: barges or other boats over 20 feet long - capable of carrying 8 or more people. Individuals counting manatees were trained by an experienced observer and had at least four supervised flights before collecting data. Individuals counting boats were briefed as to size categories prior to their first flight.

Simultaneously, ground observers were stationed at three points in Kings Bay. Two boat stations, each consisting of a 3 m (10 ft) wooden ladder tied to the deck of a boat, were anchored in the two channels used by manatees to enter and leave the South Bay. One channel is located west of Banana Island and the other west of Warden Key (Fig. 2). A third station was located midway across the bridge over the canal leading to Magnolia Springs manatee sanctuary. Observers were able to count the number of people in boats and to see or ask what activities they were planning to engage in.

Beginning at dawn and continuing through the fifth aerial survey each study day, observers at the three stations continuously recorded the following information: 1) time of each observation, 2) air and surface water temperatures at approximately half-hour intervals, 3) direction of travel of each passing boat, 4) the boat's size category, and 5) the number of people involved and the

activity they were planning to engage in (such as snorkeling, diving, observing or fishing).

Surveys were conducted on two days each week. Because the purpose of the study is to compare manatee movement patterns on days of differing levels of human use, Wednesdays and Saturdays were sampled. Wednesdays were chosen because they usually experienced lower public use levels and because, separated from the weekend by two days, any residual effects of the heavier public use on weekends would be lessened. By scheduling surveys for Wednesdays, it also was possible to reschedule on the following day in the event undesirable weather conditions prevented the Wednesday flights. Thursdays were also lower public use days.

Saturdays were chosen because they were characterized by higher levels of public use activities. In case of undesirable weather the surveys could be rescheduled for the next day, Sunday, also a higher public use day.

Two days each week were sampled when possible. Due to rain or fog not all study days were successfully completed. Successful days were those defined as containing 4 or 5 aerial surveys. Combining the two seasons there were a total of 29 successful survey days out of a possible 50 (58%). The second (complete) season accounted for 22 of the successful days out of a possible 36 (61%). There were a total of 139 separate survey flights.

The first year's field season began in January 1988 and ran through mid-March 1988. This was considered a period of pilot study, as it did not cover the entire season and was used to refine

survey techniques. However, some of the data collected were used in this report. The second field season began in November 1988 and ran through mid-March 1989. These are the months when the water temperature in the Gulf is lower and manatees typically aggregate in Kings Bay (Kochman et at., 1985).

Logistic regression (McCullagh and Nelder, 1985) was used to examine manatee distribution in the South Bay and the South Bay sanctuaries in relation to selected environmental factors, including air temperature, water temperature and number of boats. The probability of manatee occurrence in the South Bay and sanctuaries was modelled as a linear function of the environmental variables, allowing the important factors to be identified and resulting in the derivation of descriptive models. Logistic regressions were fitted using the GLIM software package (Numerical Algorithms Group, 1986). In logistic regression, the logit-transformed probability, $\underline{1}(\underline{\emptyset}_i)$, is modelled as a linear function of the explanatory variables, such that

$$\underline{1}(\underline{\emptyset}_i) = \underline{\beta}_0 + \underline{\beta}_1\underline{x}_{i1} + \underline{\beta}_2\underline{x}_{i2}, \quad \text{where}$$

$$\underline{1}(\underline{\emptyset}_i) = \ln\left(\frac{\underline{\emptyset}_i}{1-\underline{\emptyset}_i}\right)$$

Predicted probabilities, $\underline{\emptyset}_i$, can be back-transformed from logit scale as $\underline{\emptyset}_i = \frac{1}{1 + \underline{e}^{-1(\emptyset_i)}}$

To verify the required assumption that observations made on different flights were independent, variance components were estimated in a mixed model to test the effects of season,

week-within-season, and day-within-week-season on the arcsin-transformed proportion of manatees in the South Bay and the sanctuaries. Each model also contained the same fixed-effect covariates as in the logistic regressions. Variance components were based on modified maximum likelihood estimates from the SAS MIXMOD procedure (Giesbrecht, 1984) and were divided by their standard errors to yield t-statistics for significance tests.

RESULTS AND DISCUSSION

Test for independence among flights

Based on the variance component analysis, the proportion of manatees in the South Bay occurring in the sanctuaries appeared to be independent among flights. None of the variance components was significant (Table 1). Similar results were obtained for the proportion of study-area manatees in the South Bay, with the possible exception that variation among days within week-season was larger than expected ($t = 2.12$; $P < 0.05$).

Air and water temperature effects

Mean air and water temperatures were defined as the average of the temperatures measured at the two South Bay stations, averaged for each flight-hour. The temperatures taken at the Magnolia Springs station were not used in the analysis because they are unlikely to directly affect the manatees' use of the south bay

and the south bay sanctuaries. Mean air and water temperatures were highly correlated ($P < 0.001$) (Fig. 3).

Manatee use of the South Bay

The probability of study area manatees occurring in the South Bay was primarily affected by an inverse relationship with water temperature ($P < 0.05$), and was secondarily influenced by air temperature ($P < 0.01$) as indicated by logistic regression (Table 2, Figs. 4 and 5). Neither the total number of boats in the study area, nor the number of boats in the South Bay were an important correlate of manatee occurrence in the South Bay when added to the model ($P > 0.25$) (Figs. 6 and 7).

Water temperature seems to be more important than air temperature in determining manatee behavior (Irvine, 1983). Hartman (1974) found a correlation between the drop in the water temperature of the Gulf of Mexico each autumn and the increase in the number of manatees in Kings Bay. He also found that a drop in air temperature to 59°F (15°C) or lower stimulated manatees to aggregate near the springs, perhaps in anticipation of lower water temperatures to follow. This study showed that the number of manatees using Kings Bay and the South Bay springs increased as water temperatures in the bay fell. Between November and March, as long as the water temperatures in the Gulf and the bay remained cool, regardless of air temperature, some manatees usually could be found near the springs, particularly in the cooler early morning hours.

Water temperatures equal to or below 68°F (20°C) increase energetic demands on manatees, suggesting that 68°F is the minimum water temperature suitable for long-term use by manatees (Irvine, 1983). Mean water temperatures averaging equal to or below 68°F occurred on three survey days during the first season and two days during the second, in February of both years (Fig 8). On two of those days, average temperatures determined during all five morning hours were below the critical temperature. On two other days, two of five survey hours averaged below 68°F, with temperatures during the remaining hours averaging just over 68°F. The remaining day showed mean temperatures below 68°F only during the first hour. Average water temperatures at the stations tended to increase over the morning hours (Fig. 9) although on very cold days there was little or no change.

Manatee use of South Bay sanctuaries

The probability of the South Bay manatees using the sanctuaries showed a highly significant positive relationship with the number of boats in the South Bay ($P < 0.001$), in addition to an inverse correlation with water temperature ($P < 0.001$) (Table 3, Fig. 10). The addition of an air temperature variable did not significantly improve the fit of this model ($P > 0.17$). The R^2 values for the South Bay and sanctuary models were 0.3665 and 0.3565, respectively.

It is important to keep in mind that the model explains only about 36% of the variability in the relationship among water

temperature, number of boats and manatee use of sanctuaries. Additional non-random factors may also influence the relationship among these variables. Discovery of these factors may well result in development of a better predictive model. In the meantime, predictions from this model should be interpreted cautiously. Examples of factors that were not taken into account in this model because data could only be estimated were the number of people per boat, the number of snorkelers and divers among them and the intrusiveness of the swimmers. The number of boats is a fairly crude way of estimating human impact on manatees. Any management based on limiting the number of boats in an area should take into account that the number of people per boat varies with the size of the boats, days of the week, and their type of activity varies as well.

Of the 134 surveys, 35 were conducted when 25 or more boats were present. In 22 of those 35 surveys (63%), more than 50% of the manatees in the South Bay were in the sanctuaries, representing 14.5% of the study area. Of the 99 surveys during which fewer than 25 boats were present, only 35 of the 99 surveys (35%) showed more than 50% of the manatees in the sanctuaries. With only two exceptions, whenever the number of boats exceeded 35, over 50% of the manatees in the South Bay were in the sanctuaries.

Public Use Information

Observers at the ground stations collected public use information on 1436 of the thousands of boats that used Kings Bay

during the 1988-89 winter. Because the boats using Magnolia Springs probably do not have a direct affect on the manatees in the South Bay, its data are displayed separately (Table 4.). There were generally fewer people in each boat observed at the Magnolia Springs station compared to the South Bay stations. A larger ratio of residents to visitors probably accounts for the lower number of people per boat at Magnolia Springs. A large boat at Magnolia Springs is probably a privately-owned boat whereas in the South Bay, it is likely to be a rented dive barge.

There was a difference in the pattern of public use on weekday mornings versus weekend and holiday mornings. Overall, boats using the South Bay averaged about one additional person per boat on weekends and holidays compared to weekdays (Tables 5 & 6; Fig. 11). The same pattern holds true for Magnolia Springs. Most of this increase was due to an average of 2.05 more people per large boat on the weekends, probably because there were more dive barges present. The much higher average number of boats in the South Bay on weekends and holidays was due to the increase in the number of medium-sized boats, by far the largest category of boats. There were 2.96 times as many medium-sized boats on weekends and holidays, due to the high number of jon boats rented to divers and snorkelers (Fig. 12). There were also 2.91 times as many large boats present on weekends than on weekdays and 8.57 times as many small boats present on weekends. Magnolia Springs showed a similar pattern. On weekday and weekend days alike, roughly 65% of the boats passing the observation stations were in the medium category,

a little over 25% were large, and less than 10% were small canoes or rubber boats.

More boats and more people per boat resulted in a greater estimated number of people using Kings Bay on weekends and holidays than on weekdays (Fig. 13). On weekdays and weekends alike, around half the people observed were in medium-sized boats and about half were in large boats, with about 4% or fewer in the small boat category. On any given weekend or holiday, there were likely to be an average of over three times as many boats and over three times as many people present in the study area as on a weekday.

The use category that shows the most dramatic contrast between weekend and weekdays is diving (Table 7, Fig. 14). To estimate the number of people actually engaging in each activity, we used the maximum number of boats present in each category for each survey day. Because there was some unmeasured turnover throughout the morning, this still underestimates the total number of boats that used the area, but less so than other parameters, such as the mean number of boats per survey day. Combining the Magnolia Springs and South Bay data from Table 7 and multiplying the overall percentage of people engaged in each activity by the number of boats, there were an estimated nearly 5 times as many divers in the study area on weekends than on weekdays (Table 8). There were also over 4 times as many snorkelers.

These counts only covered the morning hours. Several years of public use survey reports compiled by the staff of the Chassahowitzka NWR complex show there is at least one complete

turnover of people each day. People seeking manatee encounters, therefore, commonly rent boats for a half-day rather than a full-day. An estimated number of people using the study area for the entire day would therefore be two times the number shown. Using this estimate approximately 32,480 people used the study area between November 1, 1988 and March 12, 1989 (Table 9). This is an underestimate of public use of the entire bay because the study area includes only roughly 2/3 of Kings Bay and the maximum number of boats present in any single survey is less than the total present over the 5-hour study period.

CONCLUSIONS AND RECOMMENDATIONS

The manatee's requirement for warm water sanctuaries is critical during cold periods in the winter (Cahn, 1940; Hartman, 1974; Shane, 1983). Although manatees are capable of fairly extensive forays into 68°F (20°C) or cooler water, prolonged exposure to cold water not only imposes increased energetic demands on them but can cause their deaths (Irvine, 1983; O'Shea et al. 1985). The animals arriving in Kings Bay in response to falling Gulf temperatures were therefore experiencing varying degrees of physiological stress. Unlike other marine mammals, which eat high energy and high protein diets of fish or other sea creatures and have relatively high metabolic rates, manatees eat low energy and low protein aquatic vegetation. Manatees feed for approximately 4 to 6 hours each day, probably depending on temperature, forage quality and their nutritional needs (Etheridge et al., 1985;

Bengtson, 1983). Their metabolic rate is considered unusually low, and they have high thermal conductance (Irvine, 1983). Factors which disrupt their normal routines, prevent them from feeding or resting or cause them to move unnecessarily may add stress. Manatees gathering near the warm spring heads may be under the most stress and added stress over long periods, such as for an entire winter, may affect their health and their ability to reproduce. Activities that threaten a manatee's well-being are defined as harassment under the Endangered Species Act.

Sanctuaries were implemented in Kings Bay beginning in 1980 to prevent such harassment. The Refuge enforces them during the winter months when manatees use the area. Boats and people are excluded from areas near the largest outflows so that manatees can rest and socialize in relatively warm water without interference. However, the number of animals using Kings Bay is steadily increasing. During the 1977-78 winter a maximum count of 78 manatees was recorded in Kings Bay (Kochman et al., 1985). Four years later that number had increased two-fold to 162 (December 10, 1987) (Crystal River NWR Annual Report 1987). This past winter the maximum count was 246 (December 28, 1989) (Larry Hartis, pers. comm.). The sanctuaries were not designed to accommodate this large an increase in the manatee population.

This study has shown that manatees come to Kings Bay, particularly the South Bay, in response to air and water temperatures, regardless of the number of boats present. One of the concerns that led to this study was the possibility that

manatees were being driven out of the South Bay by the weekend crowds of people. This appears not to be the case. Manatees are continuing to use the South Bay, but they are disproportionately spending time in the sanctuaries, regardless of weather conditions, in direct relationship to the number of boats present. This finding agrees with the findings of past research (Kochman, et al., 1985). The two sanctuaries in the South Bay, while representing only about 14.5% of the surface area, often contain over 50% of the manatees. On days when fewer boats are present, a larger proportion of the animals remain outside the sanctuaries feeding, resting, interacting with other manatees or interacting with people. In light of this information it is apparent that the presence of increased numbers of boats in the South Bay significantly alters the way manatees use this critical habitat by disproportionately confining them to smaller areas. This situation constitutes harassment as defined by the Endangered Species Act because normal behavioral patterns have been significantly disrupted. The following recommendations suggest placing restrictions on human waterborne activities where they conflict with the Endangered Species Act. Kings Bay is recognized as an important recreational resource, to a great degree because of the presence of manatees. The intent of these recommendations is the protection of that resource for the benefit of residents, visitors and business operators for years to come.

Recommendations

1. Limit the number of boats in the South Bay.

The predictions of the logistic regression model can be used as guidelines for estimating the maximum number of boats to be allowed in a designated area at certain specific water temperatures (see Fig. 11). The Refuge could issue a limited number of permits to boat rental companies and boat launching facilities based on current water temperatures and estimates of upcoming weather conditions. To accommodate more people, permits could be for a limited period of time. Restrictions would not prevent residents and businesses from passing through the South Bay but would be for the purpose of reducing the intensity of human activity to a level where its impact on the manatees is minimal, i.e. where they are not disproportionately using the sanctuaries.

As mentioned earlier, any restriction on the number of boats should take into account that the number of people per boat varies with the size of the boats and with the days of the week. The number of people and their behavior is likely to be an important factor.

2. Schedule hours when the South Bay is closed to boats

Restricting the number of hours boaters and divers are allowed access to manatees would solve several problems. Manatees would be assured of having sufficient time to feed and rest in warm water areas yet still be available to the visiting public for several

hours a day. Hours could be chosen that would be convenient for visitors and profitable for local businesses. Scheduled open hours could be consistent, which would allow visitors, businesses and law enforcement personnel to plan their activities. Alternatively, hours could be flexible and based on water temperatures. In cold weather, closing a portion of the South Bay during night and early morning hours when water temperatures are lowest is recommended. Closure of King's Spring, adjacent to the Banana Island sanctuary, is controversial because it is a popular dive spot and affords excellent manatee viewing, especially in the early morning hours when the animals are resting, before they are disturbed. Although King's Spring is not in itself the source of the greatest flow, the shallower areas surrounding it, particularly on the northeast side, are a favorite resting spot for large numbers of manatees (often 30 or more) on cool nights. Reduced early morning disturbance should be a priority, because temperatures are cooler, and manatees are more likely to require thermal refuge. King's Spring and the adjacent area should be protected during early morning hours, particularly when water temperatures are low.

3. Create new sanctuaries

Increasing the area of the sanctuary system would provide space for the increasing number of manatees appearing in Kings Bay each winter. Adding additional sanctuary areas would provide protected foraging areas as well. Manatees that disperse daily to feed throughout Kings Bay may be moved several times in the

course of a day as they are discovered by boaters and divers. In cold weather the time spent in unnecessary travel between foraging sites could either reduce their total feeding time or force manatees to feed at night when temperatures are significantly colder. On very cold days, manatees do not disperse to feed but remain near the springs for warmth, feeding only in the immediate area. At times of high public use, a large proportion of them further restrict themselves to the sanctuaries. The winter of 1988-89 was a very mild winter and aquatic plants were still present in the sanctuaries in March. During the preceding winter, however, the eastern end of the South Bay (including the two sanctuaries) was virtually devoid of vegetation by the end of January (Patrick Hagan, pers. comm). This appears to be true of the 1989-90 season as well. Because Florida often has one or two severe cold periods in late spring, the opportunity exists for manatees to deplete the food supplies in the sanctuaries in response to human pressure and then be forced to go without food should a late cold front confine them to the area. The risk to the manatees would be further increased if the cold front coincided with several high-use days (such as Spring Break periods when schools and colleges have vacations), when a disproportionate number of manatees use the sanctuaries. Creating foraging sanctuaries near, if not in, warm water areas could protect sanctuaries' resources from overexploitation in response to human pressure. Recommended locations for additional sanctuaries are shown in Fig. 16. These areas have been identified as manatees'

preferred foraging areas by Refuge and Sirenia Project surveys and by Kochman (1983).

Reducing the foraging pressure in the South Bay also would mean sufficient food would still be present in the event of a hurricane or severe tropical storm. In 1985, hurricane Elena forced a salt water wedge into Kings Bay, raising the salinity and killing a large proportion of the Hydrilla, the principle food for manatees in Kings Bay. This reduction occurred in August at the end of the growing season and just before the beginning of manatee migration into the area. Refuge vegetation sampling data showed that it took two years for it to return to its former abundance (USFWS, 1987). Hydrilla is an introduced aquatic plant, widely disliked by boaters for its rapid growth and propeller-entangling qualities. Despite aquatic weed control by chemical and mechanical means, it has supplanted many of the native, somewhat salt-tolerant species and now comprises 80% of the aquatic vegetation in Kings Bay (Haller and Shireman, 1982; Kochman, et al., 1985). Although under normal circumstances Hydrilla provides an abundance of food for the winter population of manatees, it can be quickly devastated by water of higher salinity. It is possible that without Hydrilla the amount of remaining vegetation in Kings Bay would not be sufficient to feed the growing number of manatees that now use the area. After the storm damage in 1985, there was concern that sufficient food would not be available for the manatees for the rest of that winter and contingency plans were made to establish additional emergency sanctuaries. Because the South Bay is the

area least likely to be affected by storm-driven salt water intrusion, care should be taken to prevent premature overgrazing of the area.

4. Expand the area of existing sanctuaries

Because manatees choose to use the South Bay at high densities regardless of the number of boats, more of the area should be included in sanctuaries. The present sanctuaries could be enlarged without unduly impacting human activities.

Outside the manatee sanctuaries in the South Bay, a boat-free buffer zone could be established where snorkelers, divers and manatees could interact. The situation at present allows motorboats, snorkelers and divers to mix in the same area. Although to my knowledge only manatees, not people, have been struck by boats, the possibility of human injury exists. A buffer zone would provide a measure of human safety that is presently missing. A well-marked channel between the protected areas, marked by buoys to be used for tying boats, could reduce the hazards of carelessly dropped anchors and reduce the number of drifting boats. Canoes, kayaks and other paddle driven craft could be allowed in the buffer zone, at the discretion of the Refuge. Any future need to restrict the number of boats in the eastern half of the South Bay could grow naturally out of such a plan by limiting the number of "parking places" and disallowing anchoring all together. Human activities not centered around the manatees should be encouraged to use the channel east of Banana Island when possible. A

sufficient channel through the South Bay would be maintained for the homeowners and businesses on the southern and eastern shores whose craft are too large for that channel.

In a recent survey of 300 visitors to Kings Bay, expanding manatee sanctuaries was the most preferred method of preventing manatee harassment (Buckingham, 1989).

5. Additional Recommendations

a) Evaluate the effects of divers and snorkelers to more closely determine human impacts.

My observations and those of others reveal a wide variation in responses of people to manatees and of manatees to people. According to Crystal River NWR Project Leader Pat Hagan, boaters who arrive in small numbers, quietly paddle in and snorkel quietly floating on the surface often attract the attention of curious manatees which respond by approaching. Those people arriving in large crowds with noisy outboard motors, wheezing SCUBA regulators and a tendency to crowd or chase the animals often find the objects of their attention heading for the sanctuaries and remaining just out of reach. Illegal actions, such as grabbing, riding, and separating a mother and calf also occur with regularity despite lists of prohibited activities available to visitors in the form of leaflets, information from local dive shops and general coverage by the media. In the recent survey of visitors to Kings Bay, over 37% reported having seen incidents of harassment (Buckingham, 1989). The actions of the boat occupants may account for much of

the variation remaining in our model. Further study is needed to narrow down these variables to a measurable component which can then be added to the model. These studies will require observations of manatee behavior in the absence of these activities for comparison. Closing the bay to all boating activity for a few select days would be the best way to accomplish this.

b) Night diving in King's Spring should be restricted. I have observed on several occasions manatees retreating from divers with lights. If dive-lights bother a large proportion of manatees, use of those lights should be limited. In cool weather, air temperatures at night can drop considerably and manatees are more likely to require thermal refuge. Therefore, night-diving in King's Spring, if it is allowed at all, should occur only when the air and water temperatures have been warm for several days, at the discretion of the Refuge. Possibly a stationary light could be placed in the spring on a few warm winter nights to see if manatees avoid it. A non-moving light may be less frightening to the manatees and may even attract them once they become accustomed to it.

c) Federal, state and local agencies need to work together to provide additional law enforcement in Kings Bay. Signs indicating speed zones should be consistent and clear, personnel schedules should be coordinated so that maximum coverage is achieved, and an effort should be made to educate members of the judiciary so that violators are prosecuted to the full extent of the law. Respondents to the public use survey in 1989 strongly

favored an increase in the number of law enforcement officers in the area (Buckingham, 1989) and many felt that fines accrued from manatee harassment violations should be used for funding additional manatee protection.

d) The idle speed zone currently in place in the eastern end of Kings Bay in the winter should be extended to include a greater proportion of the bay. On many days, especially in warm weather, snorkelers and divers are widely dispersed throughout the bay, sometimes separated from their boats and dive flags, and usually swimming just below the surface among any number of motorboats. Much of Kings Bay is currently a "slow speed" area but the recent survey of visitors to Kings Bay revealed that many of them did not know what "slow" and "idle" speeds meant (Buckingham, 1989). Half of the visitors overestimated the speed they were allowed to go in the idle speed areas. Since many people are new to the area, are renting boats they are unfamiliar with and are ignorant of the speed laws, the situation should be considered unsafe for both people and manatees. The recommendation to expand the idle speed zone to prevent manatee harassment was one of the three most popular choices by visitors.

SUMMARY

This study shows that manatees using the southern part of Kings Bay as a winter thermal refuge respond to increasing numbers of boats by moving into the boat-free sanctuaries. This response results in much higher than normal densities, particularly at times

of thermal stress. Manatees require room to rest, socialize, and eat, and a limited amount of food exists in the sanctuaries; thus, a case can be made for limiting boating activity in the South Bay, expanding the existing sanctuary system or both. These recommendations also make sense in light of the steadily increasing number of manatees aggregating in Kings Bay each winter. The present conflicts can be expected to increase if no action is taken.

The Refuge has a number of alternatives for decreasing conflict that can be implemented singly or in various combinations. It can 1) control the number of boats present at any given time, 2) schedule the time periods when boats are allowed to share the area with manatees, 3) enlarge existing sanctuaries and 4) create additional sanctuaries. Research on the effects of diving and snorkeling will lead to refinement of protection strategies. Increased law enforcement presence and an expanded idle speed zone would protect not only manatees but the public as well.

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I wish to thank Robert Sheffield of Gator Aire, Gainesville who skillfully piloted the aerial surveys. In Crystal River, I greatly appreciated the hospitality and help we received from Crystal Aero Group and Port Paradise Dive Shop.

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Table 1. Variance component t statistics from mixed model analysis.

Variance component	t statistic	
	Prop. in sanctuary	Prop. in South Bay
Season	0	0
Week (Season)	1.6	0.82
Day (Week, Season)	0.1	2.12*

* $P \leq 0.05$

Table 2. Parameter estimates for a model of the probability (Ø) that a manatee in the study area will be in the South Bay for flight i:

$l(\text{Ø})_i = \beta_0 + \beta_1$ (water temp) + β_2 (air temp), where l = the logit transformation and i = 1, ...,132.

Parameter	Estimate	s.e.	t statistic
β_0	14.46	3.998	3.617***
β_1	-0.1885	0.06285	2.999**
β_2	-0.01934	0.009453	2.046*

* $P \leq 0.01$
** $P \leq 0.05$
*** $P \leq 0.001$

Table 3. Parameter estimates for a model of the probability (Ø) that a manatee in the South Bay will be in a South Bay sanctuary for flight i:

$l(Ø)_i = \beta_0 + \beta_1$ (water temp) + β_2 (number of boats in South Bay), where l = the logit transformation and i = 1, ...,131.

Parameter	Estimate	s.e.	t statistic
β_0	15.09	3.271	4.613***
β_1	-0.226	0.047	-4.868***
β_2	0.039	0.006	6.171***

*** $P \leq 0.001$

Table 4. Number of people per boat for three size classes of boat, counted as they passes the two South Bay observation stations and the Magnolia Springs station.

Boat Size Category	Number of Boats	% of All Boats	Number of People	% of All People	People/ Boat
SOUTH BAY STATIONS					
Small	94	6.5	197	3.4	2.10
Medium	744	51.8	2368	40.5	3.18
Large	307	21.4	2408	41.2	7.84
Total	1145	79.7	4973	85.1	4.34*
MAGNOLIA SPRINGS STATION					
Small	24	1.7	43	0.7	1.79
Medium	195	13.6	533	9.1	2.73
Large	72	5.0	297	5.1	4.13
Total	291	20.3	873	14.9	3.00*

* average, not total

Table 5. Total number of boats and people per boat counted as they passed the observation stations on the nine weekdays surveyed. Average number of people per boat was calculated by dividing the total number of boats by the total number of people for each boat size category.

Boat Size Category	Boats			People			
	Number	Average/day	% of All Boats	Number	Average/day	% of All People	People/ Boat
SOUTH BAY STATIONS							
Small	7	0.78	2.7	12	1.33	1.4	1.71
Medium	141	15.67	54.9	356	39.56	40.5	2.52
Large	59	6.56	22.9	365	40.56	41.5	6.19
Total	207	23.00	80.5	733	81.44	83.4	3.54
MAGNOLIA SPRING STATION							
Small	3	0.33	1.2	7	0.78	0.8	2.33
Medium	33	3.67	12.8	85	9.44	9.7	2.58
Large	14	1.56	5.5	54	6.00	6.1	3.86
Total	50	5.56	19.5	146	16.22	16.6	2.92

• average, not total

Table 6. Total number of boats and people per boat counted as they passed the observation stations on the thirteen weekend days and holidays surveyed. Average number of people per boat was calculated by dividing the total number of boats by the total number of people for each boat size category.

Boat Size Category	Boats			People			
	Number	Average/day	% of All Boats	Number	Average/day	% of All People	People/ Boat
SOUTH BAY STATIONS							
Small	87	6.69	7.4	185	23.00	3.7	2.13
Medium	603	46.38	51.2	2012	154.77	40.5	3.34
Large	248	19.08	21.0	2043	157.15	41.1	8.24
Total	938	72.15	79.6	4240	326.15	85.4	4.50
MAGNOLIA SPRINGS STATION							
Small	21	1.62	1.8	36	2.77	0.7	1.71
Medium	162	12.46	13.8	448	34.46	9.0	2.77
Large	57	4.38	4.8	243	18.62	4.9	4.26
Total	240	18.46	20.4	727	55.92	14.6	3.03

• average, not total

Table 7. Number and percentage of total people passing the observation stations engaged in each activity.

	Diving		Snorkeling		Fishing		Observing		Total
	#	%	#	%	#	%	#	%	#
SOUTH BAY STATIONS									
Weekdays	232	35.0	60	9.1	34	5.1	215	32.5	541
Weekends	2046	52.7	654	16.8	118	3.0	500	12.9	3318
MAGNOLIA SPRINGS STATION									
Weekdays	47	7.1	37	5.6	21	3.2	16	2.4	121
Weekends	296	7.6	61	1.6	106	2.7	105	2.7	568
ALL THREE STATIONS									
Weekdays	279	42.1	97	14.7	55	8.3	231	34.9	662
Weekends	2342	60.3	715	18.4	224	5.8	605	15.5	3886

Table 8. An estimate of the number of people in the study area engaging in each activity on an average morning, weekday or weekend/holiday. This was calculated by averaging the product of the maximum number of boats in the study area in each size category during the aerial surveys and the proportion of people engaged in each activity calculated from data from the three observation stations.

	Diving	Snorkeling	Fishing	Observing	Total
Weekday	55.52	19.38	10.95	46.03	131.88
Weekend	268.24	81.85	25.80	68.95	444.84

Table 9. Estimated level of public use for the entire study area for November 1, 1988 through March 12, 1989 calculated by averaging the product of the maximum number of boats from aerial surveys and the average number of people per boat from the combined observation station data. There were 84 weekdays and 48 weekend days and holidays during this period.

	Average of Maximum Boat Counts		Average Number of People per boat		Daily Turnover		Estimated Number of People per day		Days in Season		Total
Weekdays	S = 0.89	x	1.90	x	2	=	3.38	x	84	=	284.09
	M = 12.78	x	2.53	x	2	=	64.67	x	84	=	5432.01
	L = 5.56	x	5.74	x	2	=	63.83	x	84	=	5361.62
Totals	19.23						131.88				11077.72
Weekends and Holidays	S = 5.15	x	2.05	x	2	=	21.12	x	48	=	1013.52
	M = 33.00	x	3.22	x	2	=	212.52	x	48	=	10200.96
	L = 14.08		7.50	x	2	=	211.84	x	48	=	10137.60
Totals	52.30						444.84				21352.08
									OVERALL TOTAL		32429.80

S = small, ex. canoes, kayaks, rubber boats - boats capable of carrying up to around 3 people;
M = medium-sized, ex. jon boats - boats less than 20 feet long, capable of carrying between 4 and 8 people;
L = large, ex. barges and other boats over 20 feet long, capable of carrying 8 or more people.

Fig. 1. Map of Kings Bay, Crystal River, Florida.

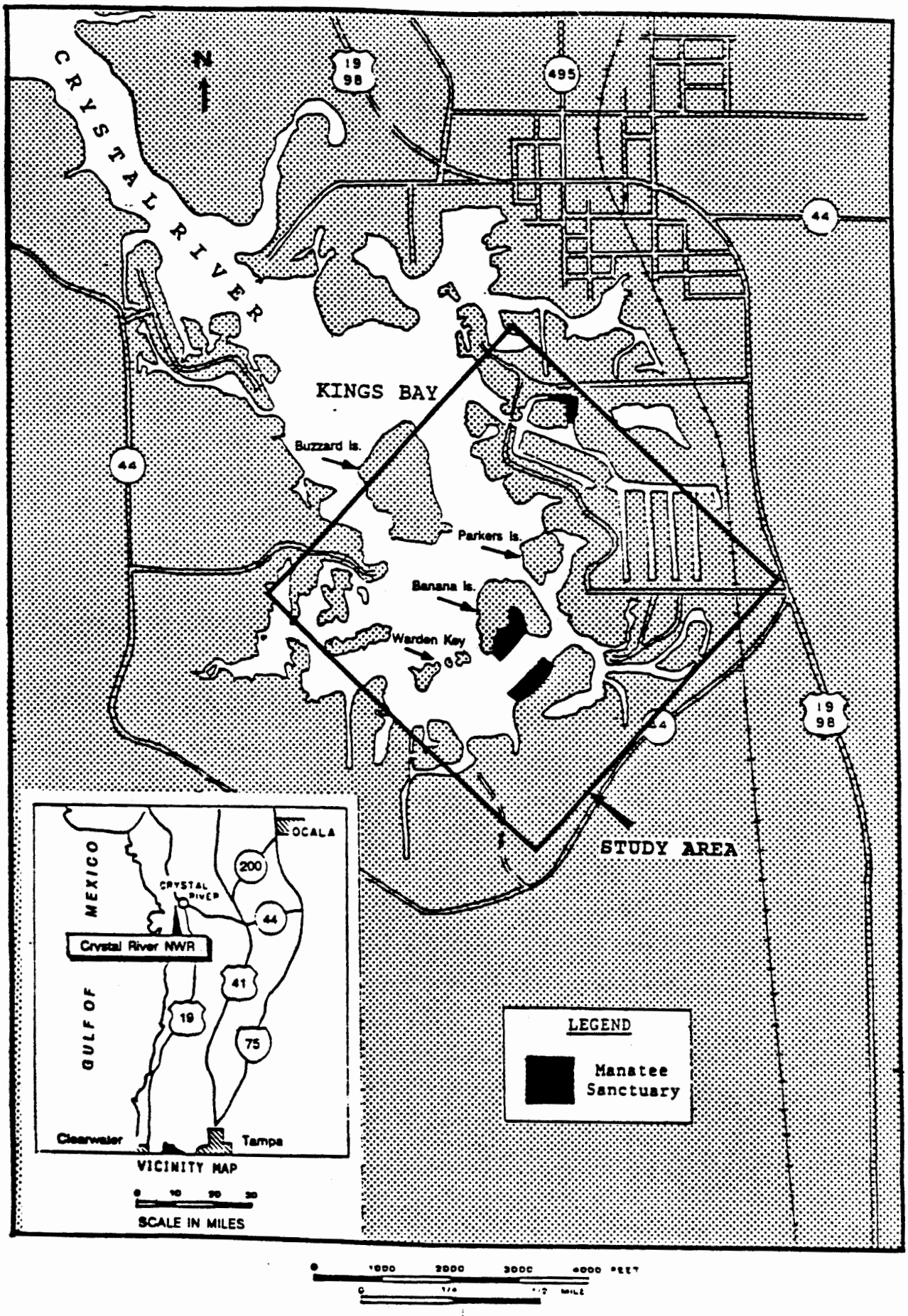


Fig. 2. Map of Study Area.

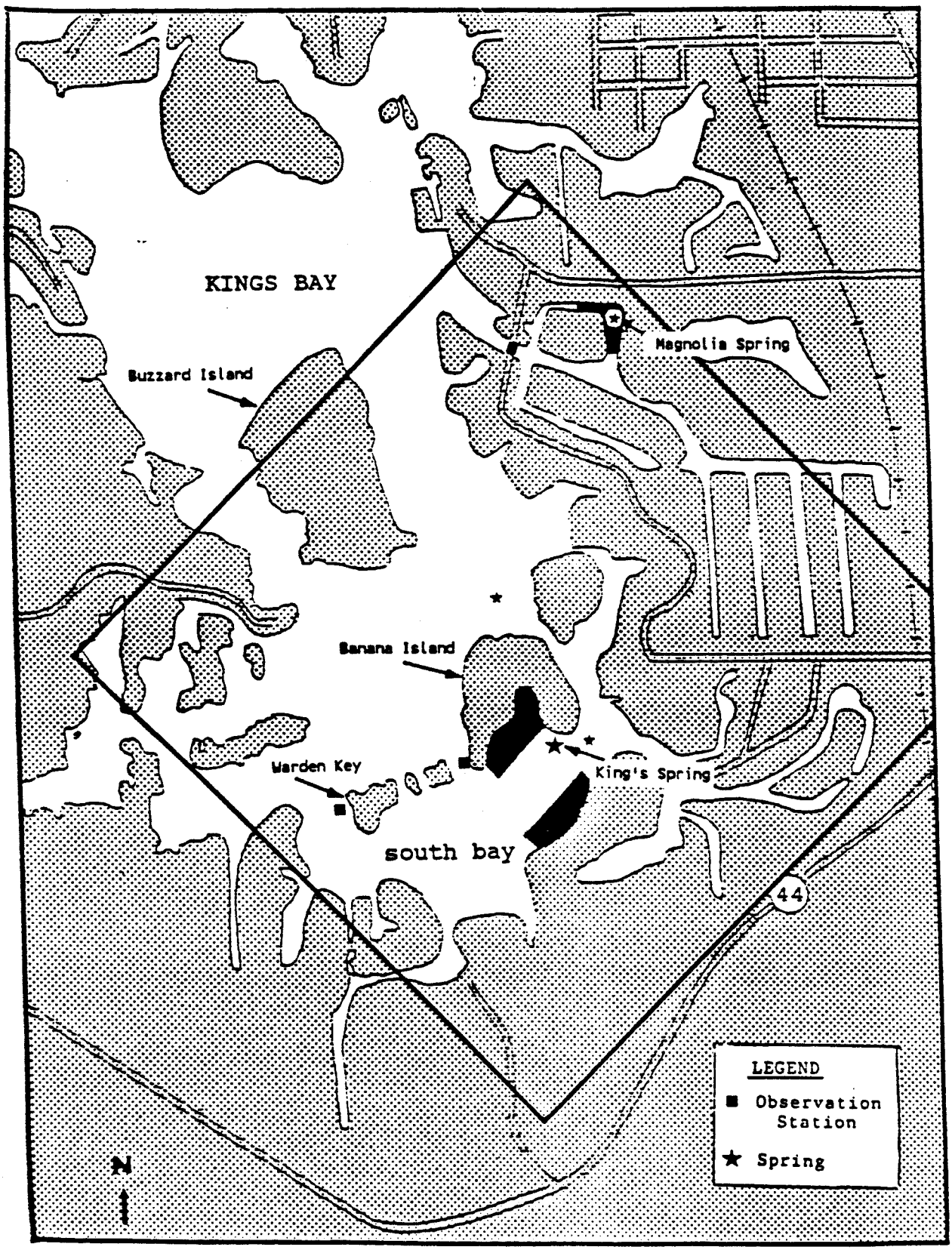


Fig. 3. Correlation between air and water temperature.

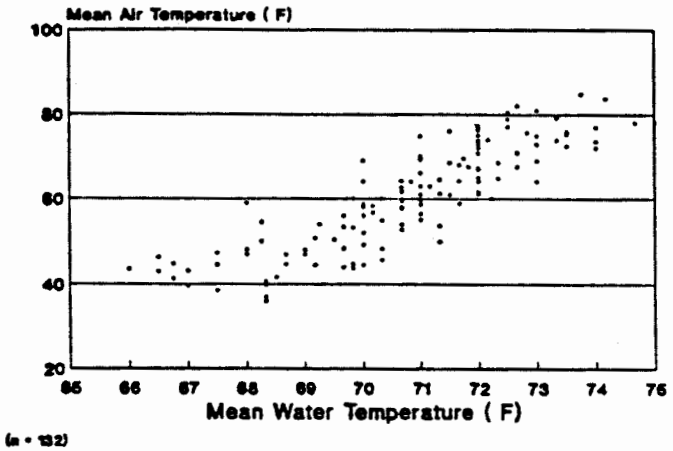


Fig. 4. Proportion of study area manatees in South Bay as a function of air and water temperatures.

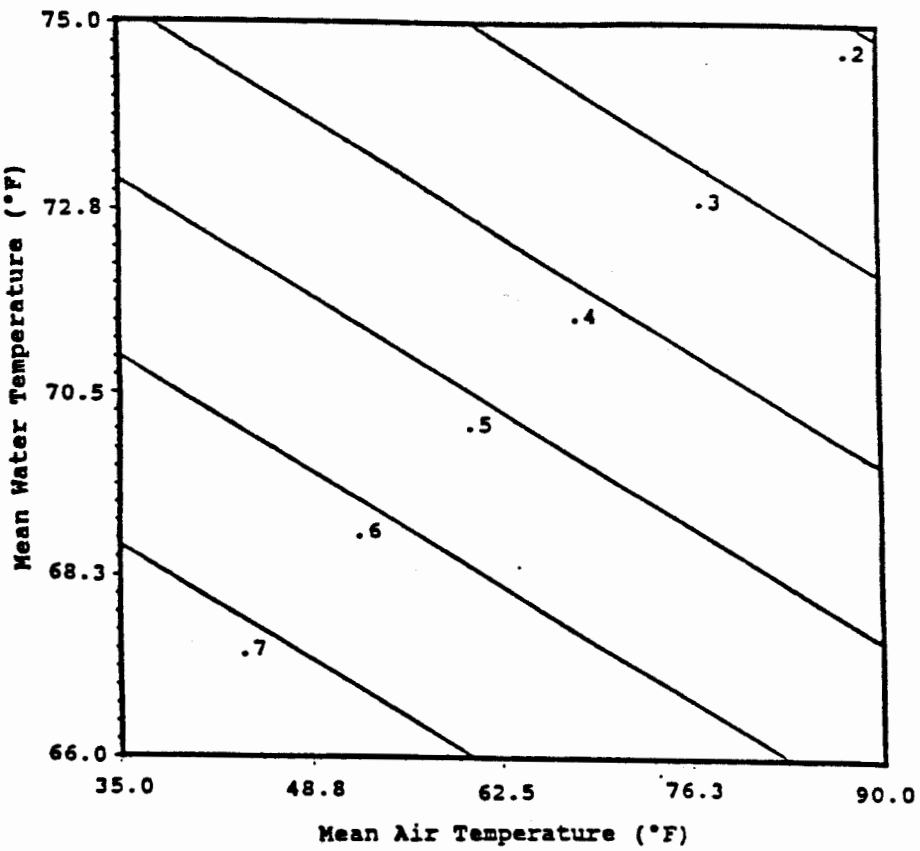
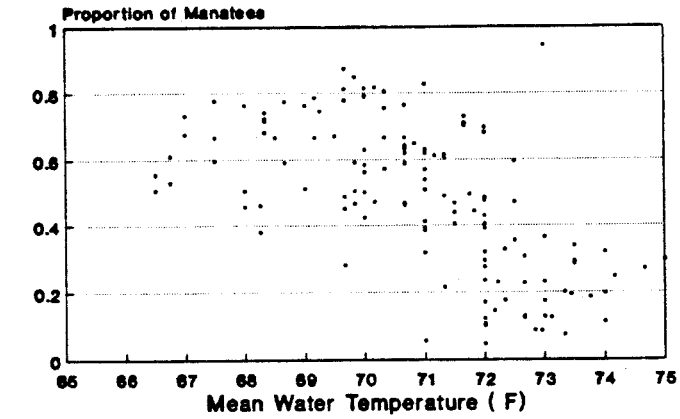
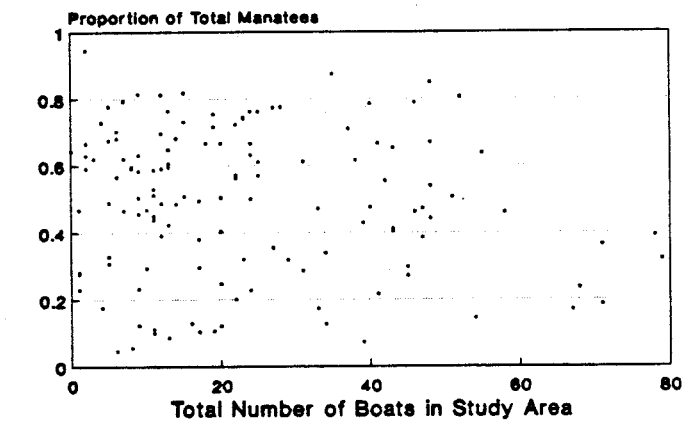


Fig. 5. Proportion of manatees in South Bay compared to water temperature.



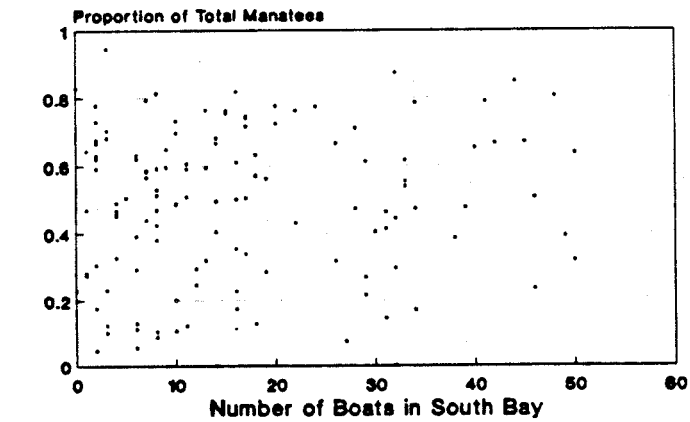
Note: Boat effect not included (N = 132)

Fig. 6. Prop. of manatees in South Bay compared to total number of boats



Temp. effects not included (n = 132)

Fig. 7. Prop. of manatees in South Bay compared to no. of boats in South Bay.



Temp. effects not included (n = 134)

Fig. 8. Minimum average water temperatures for each survey day.

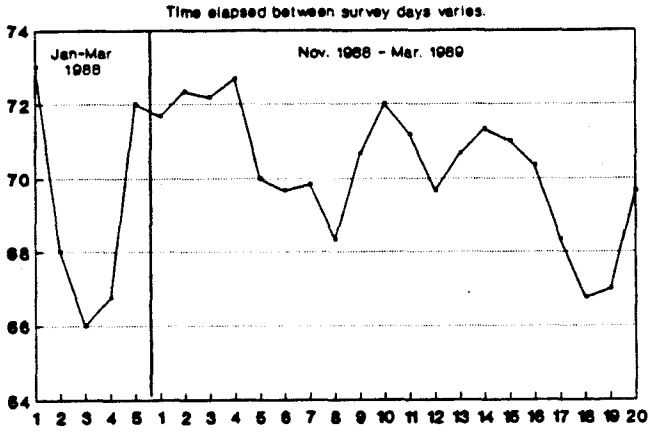


Fig. 9. Average water temperatures over morning hours.

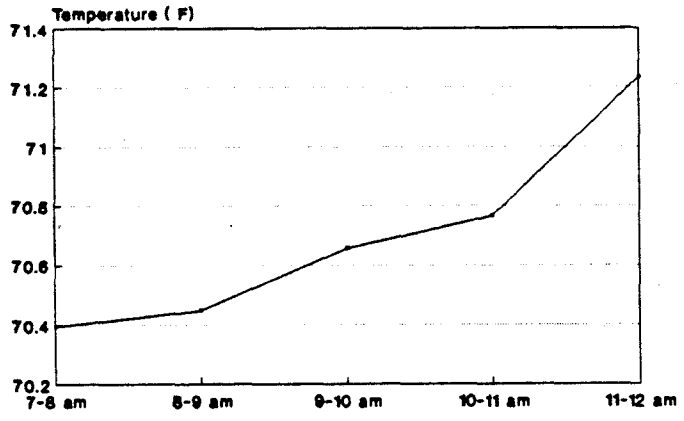


Fig. 10. Proportion of South Bay manatees in South Bay sanctuaries as a function of water temperature and boat count. A contour of the fitted response surface generated by the equation:

$$\text{Logit of probability of a manatee in the south bay being in the sanctuary} = 15.09 - 0.2264 \times (\text{water temperature}) + 0.03924 \times (\text{number of boats in south bay})$$

For a given water temperature on the Y-axis, choose the proportion of manatees in sanctuaries that may indicate boat avoidance by manatees (e.g. over 50%), follow a horizontal line from the temperature to the selected proportion and follow a perpendicular line down to find the maximum number of boats. For example, the proportion of manatees in the south bay using the sanctuaries would be expected to reach 50% at 68 degrees F when 8 boats were in the south bay.

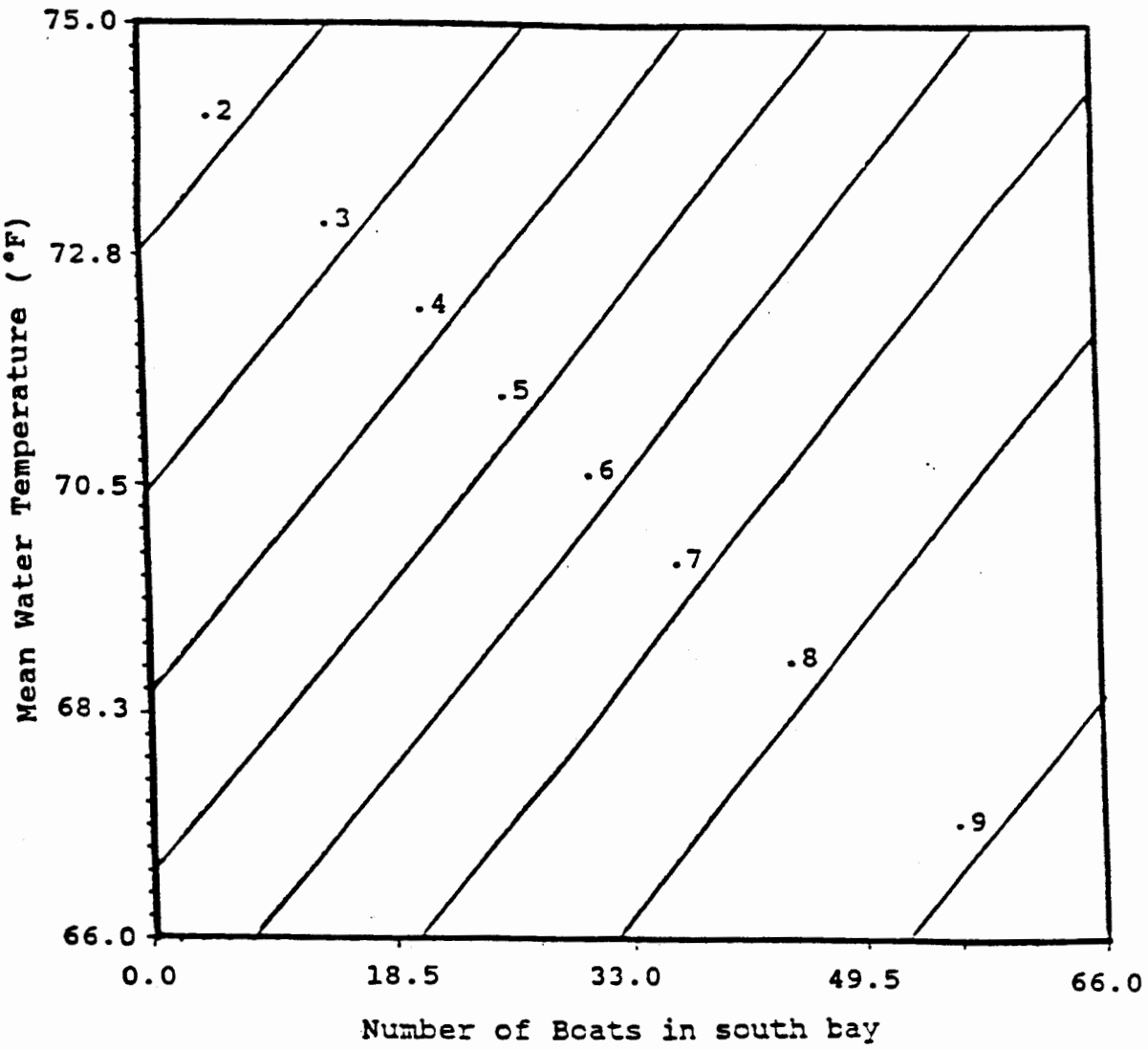
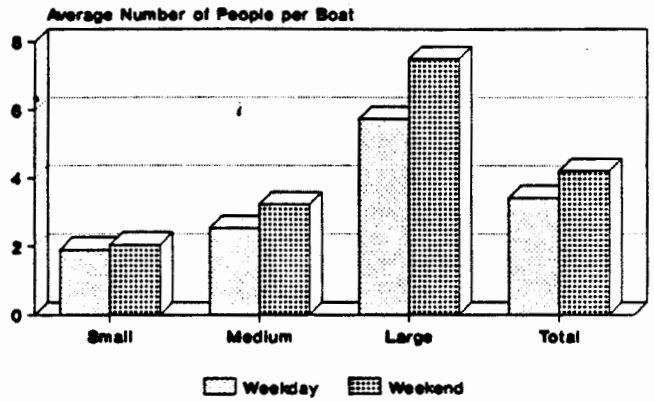
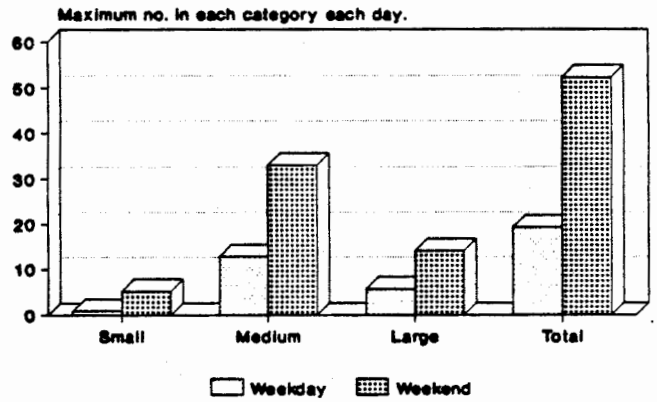


Fig. 11. Number of people per boat weekdays vs. weekends in study area



(Includes all 3 observation stations.)

Fig. 12. Estimated number of boats in study area. Weekdays vs. Weekend days



(From aerial survey data.)

Fig. 13. Average number of people/day in each boat size category.

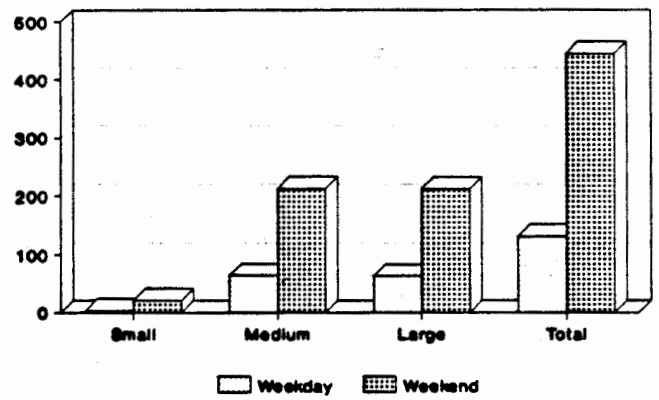
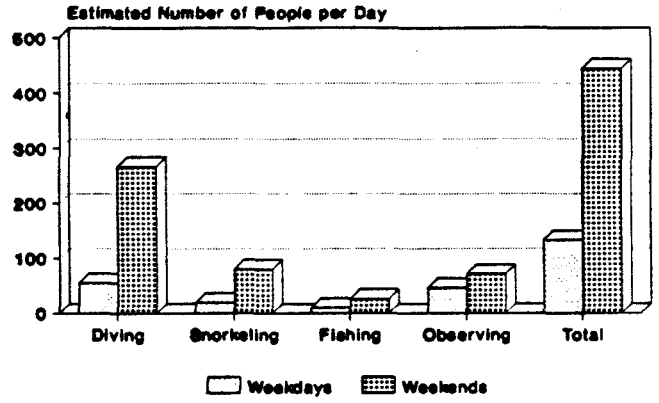


Fig. 14. Est. no. of people engaged in each activity - Weekdays vs. Weekends



(From aerial and ground station data.)

Fig. 15. Manatee Sanctuaries - Current and Recommended.